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Alpha-tocopherol concentrations and case life of lamb muscle as influenced by concentrate or pasture finishing[1]

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ABSTRACT: Two experiments were conducted to evaluate α-tocopherol accumulation in muscle of lambs finished on pasture or concentrates. The objective for Exp. 1 was to compare accumulation of α-tocopherol in the longissimus muscle of pasture-fed lambs to that of lambs fed three concentrations (15, 150, and 300 IU/kg of DM) of supplemental vitamin E (all *rac* α-tocopheryl acetate) in all-concentrate diets. The objective in Exp. 2 was to investigate the effect of duration of supplemental vitamin E feeding on α-tocopherol content and color change during display case storage of lamb muscle. Treatments evaluated in Exp. 2 were: 15 IU of supplemental vitamin E/kg DM fed to finish; 15 IU/kg followed by 300 IU/kg of DM during the last 21 d; and 15 IU/kg DM until 7 d prior to finish, then 300 IU/kg DM. In Exp. 1, α-tocopherol concentration of rotational grazed alfalfa and perennial ryegrass averaged 137 and 169 mg/kg of DM. Vitamin E treatments for lambs fed concentrate diets did not affect ADG ($P > 0.15$), but ADG was greater ($P < 0.01$) for concentrate-fed lambs than for grazing lambs. For the concentrate-fed lambs, α-tocopherol in longissimus muscle increased quadratically ($P < 0.05$) as dietary concentrations of vitamin E increased. Predicted maximum α-tocopherol concentration in muscle occurred at about 400 IU/kg of diet DM. Longissimus muscle from lambs grazing alfalfa or ryegrass had similar ($P > 0.50$) α-tocopherol concentrations, and those concentrations were similar to values obtained when the concentrate diet supplemented with 150 IU of vitamin E/kg was fed. In Exp. 2, no differences ($P > 0.10$) in ADG were observed. Concentrations of longissimus α-tocopherol were highest when 300 IU supplemental vitamin E was fed for 21 d prior to slaughter. During a 6-d display period, semimembranosus steaks from lambs fed 300 IU of supplemental vitamin E/kg for either 7 or 21 d had higher a* and b* color readings than steaks from lambs fed 15 IU/kg of supplemental vitamin E. Increased consumption of vitamin E either via pasture or supplementation results in higher α-tocopherol concentrations in meat.

Key Words: Color, Lambs, Pastures, Tocopherols, Vitamin E

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Introduction

Supplementation of diets with vitamin E in excess of NRC requirements increases the α-tocopherol concentration of muscle and improves color stability of beef (Arnold et al., 1992) and lamb meat (Wulf et al., 1995; Guidera et al., 1997). α-Tocopherol slows the conversion of oxymyoglobin to metmyoglobin in beef thereby slowing the development of an undesirable brown color in displayed beef (Lanari et al., 1994). Most concentrate-based diets that have not been supplemented with vitamin E have low α-tocopherol concentrations; however, fresh forages naturally contain high concentrations of α-tocopherol. Lambs grazing fresh forage might have high α-tocopherol concentrations in their muscle resulting in improved oxidative and color stability of the meat without having to feed supplemental vitamin E.

For economic reasons, dietary strategies that result in high concentrations of α-tocopherol in muscle with minimal vitamin E supplementation would be useful. In beef cattle, the rate and duration of vitamin E supplementation affect muscle α-tocopherol concentrations (Arnold et al., 1992). In sheep, supplementation of 200 to 500 IU of vitamin E/d increases muscle α-tocopherol (Hidiroglou and Charmley, 1990; Wulf et al., 1995). The effect of duration of vitamin E supplementation and pasture finish on α-tocopherol concentrations and color

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Table 1. Ingredient composition of the all concentrate diet with 15 IU of supplemental vitamin E/kg of DM. All ingredients except the whole shelled corn were combined and pelleted (Exp. 1 and 2)[a]

Ingredient	% of DM
Whole shelled corn	83.462
Soybean meal, 44% CP	12.700
Urea	0.200
Limestone	1.397
Dicalcium phosphate	1.167
Ammonium chloride	0.500
Trace mineralized salt	0.500
Vitamin A premix (30,000 IU/g)	0.007
Vitamin D premix (3,000 IU/g)	0.018
Lasalocid premix[b] (150 mg/kg)	0.018
Vitamin E premix (44 IU/g)	0.031

[a]The 150 and 300 IU of supplemental vitamin E/kg diets were identical except that the vitamin E premix was increased to 0.310 and 0.620% (with a concomitant decrease in shelled corn), respectively.
[b]Alpharma, Inc., Ft. Lee, NJ.

of muscle during display case storage has not been studied in lambs.

The objectives of this study were to compare concentrations of α-tocopherol in meat from lambs grazing pasture to those fed concentrate diets with different concentrations of vitamin E and to determine the effect of duration of feeding lambs high concentrations of vitamin E during the finishing phase on muscle α-tocopherol concentrations and meat color.

Materials and Methods

Care of lambs and ruminally cannulated steers and the research protocols used in these experiments followed accepted guidelines (Consortium, 1988).

Experiment 1

Pastures. Alfalfa (*Medicago sativa* L.; cv. Cimeron) and perennial ryegrass (*Lolium perenne* L; cv. Bastain) were seeded as pure stands in 1995. Phosphorus (54 kg/ha) and K (206 kg/ha) fertilizer was applied to all paddocks in the fall prior to the grazing season. Nitrogen was applied to ryegrass paddocks in April, June, and August (67 kg/ha each time). Each pasture was 0.62 ha. Rotational stocking was used to maintain high forage quality (high CP and in vitro digestibility and low fiber) throughout the summer and autumn. Alfalfa pastures were divided into eight paddocks with 23 to 25 d regrowth between grazing events. Ryegrass pastures were divided into four paddocks with 12 to 16 d regrowth between grazing events. Grazing lambs had access to water, shade, and a mixture of dicalcium phosphate and trace mineral salt (containing Se).

Concentrate Diets. Diets were formulated to contain approximately 83% whole shelled corn (*Zea maize* L.) and 17% pelleted supplement (Table 1). Vitamin E (all *rac* α-tocopheryl acetate) was incorporated into the pellets to provide 15 IU [the NRC (1985) recommendation for lambs], 150 IU, or 300 IU of supplemental vitamin E/kg of diet DM. The amount of feed offered daily was adjusted frequently to keep orts to approximately 0 kg/d.

Animals. Thirty wether and thirty ewe lambs (Hampshire × Targhee) were assigned (blocked by gender) to the two grazing treatments and the three all-concentrate diets. Before the experiment, all lambs were housed in dry lots with their ewes and provided a standard creep feed (15 IU of supplemental vitamin E/kg of DM). Lambs were vaccinated against tetanus and *Clostridium perfringens* types C and D. The trial began May 28 with heavier lambs assigned to pasture treatments (average initial BW = 30.0 kg) than to the concentrate treatments (23.1 kg) because of the expected slower rate of gain for the forage-fed lambs. Forage diets had two replicates of six lambs each, and concentrate diets had three pens of four lambs each. One lamb from each concentrate treatment and from the ryegrass treatment and two lambs from the alfalfa treatment were removed from the experiment for factors unrelated to treatment. Full BW of all lambs were measured on two consecutive days at the start of the trial and interim full weights were recorded every 14 d and at the end of the trial. Lambs were finished to a targeted final BW of 52 kg for drylot (70 d on experiment; August 11) and 55 kg for pasture-fed lambs [89 d (September 8) for lambs on alfalfa and 125 d (October 12) for lambs on ryegrass].

Forage and Feed Analyses. Herbage samples were collected on July 1, July 27, and September 9 from three random sites within paddocks immediately before grazing, composited, and lyophilized. Random grab samples of concentrate diets were collected over the course of the trial and composited. Concentrate and lyophilized herbage samples were ground to pass a 2-mm screen in a Wiley mill and were analyzed for DM and ash (AOAC, 1990); total N (Carlo-Erba Ea 1108 CHNS elemental analyzer, Fisons Instruments, Beverly, MA); ADF and NDF (Goering and Van Soest, 1970; Van Soest et al., 1991); and in vitro OM disappearance (IVOMD) (Tilley and Terry, 1963; Moore, 1970). The two-stage IVOMD procedure used ruminal fluid obtained from two ruminally cannulated steers fed orchardgrass (*Dactylis glomerata* L.), alfalfa hay, and a small amount of cracked corn grain with minerals and vitamins. Samples of lyophilized herbages and the three concentrate diets were sent to the University of Wisconsin Soil and Plant Analysis Lab for determination of α-tocopherol concentration using HPLC methods (Arnold et al., 1993).

Carcass Characteristics. Lambs were transported to a local packing plant the day before harvest. One pen of lambs from each concentrate treatment were harvested on a single day, and all lambs fed the concentrate treatments were harvested over a 3-d period. All lambs on the alfalfa treatment were harvested on a single day, and 10 d later all lambs on the ryegrass treatment

were harvested. Carcass data were collected from three randomly selected lambs per pen for the concentrate treatments and from four lambs (random) from one replicate of the ryegrass and alfalfa treatments and from five lambs (random) from the other replicate. Lambs were weighed immediately before harvest and hot carcass weight recorded postharvest. After a 24-h chill period (2°C), backfat thickness, leg conformation, % kidney, pelvic, and heart fat, body wall thickness, longissimus muscle area, yield grade, and USDA quality grade were determined. On d 3 postharvest, a trimmed, boneless loin chop (representing longissimus) was obtained from the right half of three lamb carcasses in each treatment group and stored at –60°C until all samples were obtained and then shipped on dry ice to the University of Wisconsin Soil and Plant Analysis Lab for determination of α-tocopherol concentrations using HPLC (Liu et al., 1996).

Experiment 2

Drylot Diets. The 15 and 300 IU/kg concentrate diets fed in Exp. 1 were used (Table 1). Dietary regimens were 1) concentrate diet containing 15 IU vitamin E/kg DM until finish, 2) concentrate diet with 15 IU/kg until 21 d prior to finish, then the 300 IU/kg diet until finish, or 3) concentrate diet with 15 IU/kg until 7 d prior to finish then the 300 IU/kg diet until finish. Regimens were fed for an average of 71 d.

Animals. Twenty-four fall-born Polypay lambs were used with two pens per treatment and four lambs per pen. Lambs were assigned by BW with an equal numbers of wether and ewe lambs in each pen. Lambs were weighed on two consecutive days at the start of the trial in January. Full BW were recorded every 14 d and at harvest (March 9 and 23). Targeted finished weight before harvest was 47 kg.

Carcass Characteristics. Lambs were transported to The Ohio State University Meat Lab in Columbus for harvest and collection of final BW. On d 3 postharvest, a trimmed, boneless loin chop was obtained from the right half of each carcass and stored at –60°C until α-tocopherol analysis. The semimembranosus muscle was dissected from both legs and three steaks (1.9 cm thick) per leg were cut from the muscle and left to bloom for 30 min (Wulf and Wise, 1999). One steak per lamb was used to determine pH and colorimetric measurements at time 0 (after 30 min bloom). The other five steaks per lamb were commercially wrapped and transported on ice to Wooster, OH, where they were stored in a meat case at 3°C under fluorescent lighting for 1, 2, 3, 4, or 6 d. After the appropriate storage period, a single steak per lamb was unwrapped, and pH and colorimetric measurements were taken. After measurements were taken, the steak was discarded. The pH was measured using a Meatcheck 160 pH meter (Sigma Electronic GmbH Erfurt, Germany) equipped with a puncture-type combination electrode (LoT 406-M6-DXK-S7/25 Mettler-Toledo GmbH, Urdorf, Switzerland). Color readings were taken in L* (white and black spectrum), a* (red and green spectrum), and b* (yellow and blue spectrum) color space (Wulf and Wise, 1999) using a colorimeter (Minolta Chroma Meter CR-300, Minolta Corp., Ramsey, NJ) with approximately 50-mm-diameter aperture. The colorimeter was calibrated before each use. The pH and colorimeter measurements on meat case-stored samples were taken initially and on d 1, 2, 3, 4, and 6 after storage. Visual assessments of semimembranosus steaks and loin chops were made on d 1, 3, and 6 by a six-member panel (blind to treatments) for lean color (1 = dark brown, 8 = bright red) and overall appearance (1 = extremely undesirable, 8 = extremely desirable) based on the scaling outlined in Guidelines for Meat Color Evaluation (AMSA, 1991).

Statistical Analysis. Data from Exp. 1 were analyzed statistically using PROC MIXED of SAS Version 8 (SAS Inst. Inc., Cary, NC). Pen or pasture was the experimental unit and the model included treatment (4 df) and error (8 df). The treatment effect was partitioned into four contrasts: 1) alfalfa vs ryegrass, 2) grazing treatments vs concentrate treatments, 3) linear effect of dietary vitamin E (concentrate treatments only), and 4) quadratic effect of dietary vitamin E (concentrate treatments only). The relationship between dietary concentrations of α-tocopherol and concentrations in muscle was quantified using PROC REG of SAS. In Exp. 2, performance data were analyzed statistically using PROC MIXED with treatment (2 df) as a main effect, with pen within treatment (3 df) as the error term. Subjective visual scores, pH, and colorimeter data were analyzed using PROC MIXED with treatment (2 df), day of display (2 or 5 df), and treatment by day interaction in the model. Pen within treatment was used to derive the error terms. Day of display was considered a repeated measure (covariance structure used was spatial gausansian). Treatment effects in Exp. 2 were partitioned into two contrasts: effect of vitamin E supplementation (15 IU/kg treatment vs 300 IU/kg treatments) and effect of duration of supplementation (21 d of 300 IU/kg vs 7 d of 300 IU/kg).

Results and Discussion

Experiment 1

Nutrient composition data for the forages and feeds are presented in Table 2. The measured total α-tocopherol (supplemental plus basal) concentrations in the three concentrate diets were similar to anticipated concentrations. Essentially all the α-tocopherol in those diets came from all *rac* α-tocopheryl acetate. Therefore, a conversion factor of 1 mg α-tocopherol/kg = 1.1 IU of vitamin E/kg (USP, 1999) was used resulting in 19, 202, and 367 IU of vitamin E/kg DM for the 15, 150, and 300 IU/kg diets, respectively. Daily DMI by lambs did not differ ($P > 0.10$) among the three concentrate-fed groups (mean = 1.48 kg, SEM = 0.05, data not shown). Intake of α-tocopherol averaged 25, 272, and

Table 2. Chemical composition and in vitro OM digestibility (IVOMD) of the forages (Exp. 1) and all-concentrate diets (Exp. 1 and 2). All values on a DM basis

	Concentrate diets			Grazed forages		
Measure	15 IU	150 IU	300 IU	Alfalfa	Ryegrass	SEM[a]
CP, %	15.6	15.0	13.8	28.4	30.6	1.7
NDF, %	20.4	20.5	19.8	21.4	37.7	3.8
ADF, %	9.1	8.8	5.2	13.5	20.6	1.8
IVOMD, %	94.6	89.5	90.2	74.4	74.7	1.6
α-tocopherol, mg/kg	17	184	334	137	169	12.5

[a]SEM of grazed forages based on three sampling dates (July 1, July 27, and September 4).

494 mg/d (equivalent to 28, 299, and 543 IU of vitamin E/d) for the 15, 150, and 300 IU/kg diets.

The mean α-tocopherol concentration in alfalfa was 137 mg/kg DM (111, 173, and 126 mg/kg DM for samples taken on July 1, July 27, and September 4) and 169 mg/kg DM for ryegrass (148, 167, and 193 mg/kg DM for the July 1, July 27, and September 4 samples). These values are within the range reported for fresh grasses and grass/alfalfa mixtures (Mutetikka and Mahan, 1993; Tramontano et al., 1993). The α-tocopherol in the forages would be *RRR*-α-tocopherol; therefore, 1 mg α-tocopherol would equal 1.49 IU of vitamin E (USP, 1999), which equals 204 and 252 IU of vitamin E/kg DM for the alfalfa and ryegrass, respectively.

Lamb Performance and Carcass Characteristics. Lambs fed the three concentrate diets had similar ($P > 0.15$) ADG (Table 3) and required 70 d to reach finish weight. In a previous experiment, vitamin E supplementation at 1,000 IU/d, but not 500 IU/d, decreased ADG in finishing lambs (Wulf et al., 1995). As expected (Arnold and Meyer, 1988; McClure et al., 1995), the ADG of lambs fed the concentrate diets were higher ($P < 0.01$) than pasture-fed lambs. Lambs fed alfalfa or ryegrass required 89 and 125 d, respectively, to reach finish weight. The ADG of lambs grazing alfalfa was numerically greater ($P < 0.12$) than the ADG of lambs grazing ryegrass. The lack of a statistical difference between lambs grazing ryegrass and those grazing alfalfa was probably caused by inadequate replication. McClure et al. (1995) reported higher ADG for lambs grazing alfalfa than for those grazing cool season grasses.

Vitamin E treatment had no effect ($P > 0.15$) on carcass data and only a few differences were observed between concentrate- and pasture-fed lambs and between alfalfa and ryegrass treatments (Table 3). Dressing percent was lower ($P < 0.01$) and kidney and pelvic fat percent was higher ($P < 0.06$) for lambs grazing ryegrass than for those grazing alfalfa, but the differences were not large. Other carcass measurements were similar ($P > 0.10$) among treatments. Dressing percentage were higher for concentrate- finished lambs than pasture-finished lambs. Dressing percentage may have been

Table 3. Performance and carcass characteristics of lambs finished on all-concentrate diets or alfalfa or ryegrass pastures (Exp. 1)

	All-concentrate[a]			Pasture			Contrast[b], *P*<	
Item	15 IU	150 IU	300 IU	Alfalfa	Ryegrass	SE[c]	C vs P	A vs R
No. of pens	3	3	3	2	2			
Initial BW, kg	23.0	23.3	23.0	31.2	28.5	2.55	0.01	0.69
Final BW, kg	52.2	50.8	51.6	56.0	55.1	2.34	0.03	0.31
ADG, g	422	393	408	278	213	36.8	0.01	0.12
Carcass wt, kg	27.6	28.2	27.8	30.2	27.8	1.30	0.18	0.09
Dressing percent	53	54	53	53	50	0.9	0.02	0.01
Backfat, mm	5.5	5.9	5.7	7.0	6.2	0.90	0.13	0.42
Kidney, pelvic, heart fat, %	3.5	3.5	3.4	3.3	3.8	0.23	0.76	0.06
Body wall thickness, mm	21.1	20.7	20.4	19.8	21.6	1.62	0.97	0.31
Longissimus area, cm^2	16.9	17.0	16.6	18.0	15.7	1.48	0.99	0.17
Quality grade[d]	10.8	10.8	11.4	10.8	10.8	0.46	0.47	0.99
Yield grade	3.5	3.6	3.4	3.8	3.7	0.24	0.09	0.69
α-tocopherol[e], mg/kg	0.57	3.22	4.19	2.50	2.15	0.623	0.33	0.52

[a]Concentration of supplemental vitamin E/kg of diet DM.
[b]Contrasts: C vs P = concentrate diets vs pasture diets; A vs R = ryegrass vs alfalfa. NS = $P > 0.15$. Linear and quadratic contrasts for effects of dietary vitamin E (concentrate diets only) were not significant ($P > 0.15$) except for α-tocopherol concentration.
[c]To determine the standard error of the mean divide the SE by the square root of the number of pens for the respective treatment.
[d]Encoded as 10 = low Choice, 11 = average Choice, and 12 = high Choice.
[e]Concentration (wet basis) of α-tocopherol in a trimmed longissimus chop. Linear ($P < 0.01$) and quadratic ($P < 0.09$) effects of dietary vitamin E (concentrate diets).

influenced by gut fill, which is inversely related to dressing percentage. Other factors include degree of muscling and fatness. In general, concentrate-fed lambs would tend to have less gut fill due to higher energy restricting intake compared to forage-finished lambs. Trends for higher yield grades with pasture finishing were probably related to numerically higher fat thickness measurements than concentrate-finished lambs.

α-Tocopherol in Meat. In the concentrate-fed lambs, mean α-tocopherol concentrations in longissimus increased linearly ($P < 0.01$) with increasing vitamin E supplementation (Table 3). An analysis of the residuals from a linear regression analysis, however, revealed that a linear relationship was inappropriate (data not shown). A quadratic function relating the concentration of dietary vitamin E (expressed as mg of α-tocopherol/kg DM or as IU of vitamin E/kg DM) for the concentrate treatments to the concentration of α-tocopherol in longissimus resulted in a random distribution of residuals. The quadratic function (Figure 1) had a predicted maximum concentration of α-tocopherol in longissimus when dietary vitamin E was 403 IU/kg DM (369 mg α-tocopherol/kg DM). Based on measured DMI, predicted maximum concentration of α-tocopherol in longissimus occurred at an intake 584 IU of total vitamin E (535 mg α-tocopherol)/d. Wulf et al. (1995) reported no difference in α-tocopherol concentration of lean tissue when finishing lambs were fed either 500 or 1000 IU of vitamin E/d for 56 d (DMI and total concentration of dietary vitamin E were not reported). Hidiroglou and Charmley (1990) found no differences in α-tocopherol concentrations in the neck muscle of lambs fed 200, 300 and 400 IU of vitamin E/d for 2 mo. The quadratic function fit the data well up to the maximum dietary concentration of this study. No available data, however, suggest that muscle α-tocopherol decreases as dietary concentrations increase above approximately 400 IU/kg of DM. Most likely, the correct relationship contains a quadratic function with a plateau.

Mean α-tocopherol concentrations in the longissimus chop from lambs grazing alfalfa and ryegrass were similar ($P > 0.15$). One longissimus sample from the ryegrass treatment had an extremely low α-tocopherol concentration (Figure 1). Although this value is suspect, we could find no reason to exclude it. The concentrations of α-tocopherol in longissimus from grazing lambs were between the concentrations found in lambs fed the 15 and 150 IU of supplemental vitamin E/kg concentrate treatments. Because DMI by lambs on pasture was not measured, comparing the relationship between dietary concentrations of vitamin E or α-tocopherol for pasture-fed lambs to that of concentrate-fed lambs is tenuous. Dry matter intake as estimated using forage composition (Table 2) and NRC equations (NRC, 1987) was 1.4 and 1.2 kg/d for lambs grazing alfalfa and ryegrass, respectively. The estimated DMI of lambs grazing alfalfa was essentially equal to concentrate-fed lambs (1.4 vs 1.48 kg/d), but estimated DMI of lambs grazing ryegrass was about 20% less than the DMI of the concentrate-fed lambs. After adjusting vitamin E and α-tocopherol dietary concentrations for estimated DMI differences (i.e., concentration in ryegrass was reduced 20% to account for lower estimated DMI), the concentration of α-tocopherol in the longissimus of lambs fed alfalfa or ryegrass fit the relationship between dietary α-tocopherol concentration and longissimus α-tocopherol observed for the concentrate fed lambs (Figure 1A). The concentrate diet supplemented with 150 IU of vitamin E/kg, the alfalfa, and the ryegrass (adjusted for estimated DMI differences) all contained about 200 IU of vitamin E/kg of DM and all resulted in similar concentrations of α-tocopherol in the longissimus (Figure 1B). These results suggest that the USP conversion of 1.49 IU of vitamin E/mg of *RRR*-α-tocopherol is appropriate

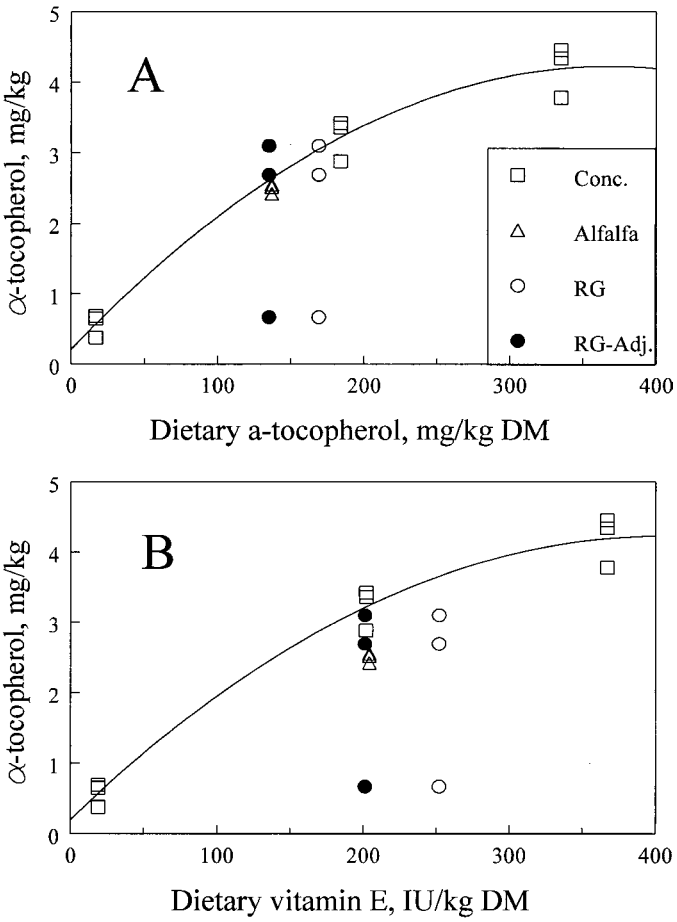

Figure 1. The relationship between concentrations of α-tocopherol in longissimus muscle from lambs and dietary concentration of α-tocopherol (A) or vitamin E (B). The solid lines represent regression equations (A; $Y = 0.212 + 0.0218X - 0.0000300X^2$; $R^2 = 0.98$; $P < 0.01$: B; $Y = 0.203 + 0.020X - 0.0000247X^2$; $R^2 = 0.98$, $P < 0.01$). Only data from lambs fed concentrate diets (Conc) were used in the regression. RG = data from lambs grazing ryegrass and RG-Adj. = data from lambs grazing ryegrass but concentrations were reduced 20% based on estimated differences in DMI (Exp. 1). Each point represents data from a single lamb.

Table 4. Performance and longissimus α-tocopherol concentrations of lambs fed all concentrate diets with different vitamin E treatments (Exp. 2)

	Treatment[a]				Contrasts[b] (P <)	
Item	15 IU	300 IU (7 d)	300 IU (21 d)	SEM	SUP	DUR
No. of pens	2	2	2			
Initial BW, kg	25.5	26.8	24.1	0.76	0.96	0.10
Final BW, kg	46.1	47.6	48.0	0.91	0.21	0.78
DM intake, kg/d	1.23	1.30	1.28	0.044	0.73	0.31
ADG, g	304	340	320	12.3	0.18	0.33
α-tocopherol, mg/kg wet wt	0.89	1.91	2.89	0.092	0.01	0.01

[a]15 IU = 15 IU of supplemental vitamin E/kg DM during the finishing phase; 300 IU (7 d) = 15 IU of supplemental vitamin E/kg of DM and then 300 IU/kg of DM during the last 7 d of the finishing phase; 300 IU (21 d) = 15 IU of supplemental vitamin E/kg of DM and then 300 IU/kg of DM during the last 21 d of the finishing phase.

[b]SUP = contrast comparing 15 IU treatment to the two 300 IU treatments; DUR = contrast comparing duration of vitamin E supplementation (i.e., 300 IU (7 d) vs the 300 IU (21 d) treatments). NS = $P > 0.15$.

when the target tissue is longissimus of lambs. The effect of different forms of dietary α-tocopherol on muscle concentrations of α-tocopherol has not been investigated adequately. In one study, concentrations of α-tocopherol in neck muscle of lambs were equal when 300 mg of α-tocopherol from all *rac* α-tocopheryl acetate (330 IU of vitamin E/d) or 300 mg of D-α-tocopherol from D-α-tocopheryl acetate (449 IU of vitamin E) were fed (Hidiroglou et al., 1994). In that same study, however, concentrations of α-tocopherol were higher in the gluteus medius when the lambs were fed D-α-tocopherol acetate compared with those fed all *rac* α-tocopheryl acetate. Hidiroglou et al. (1988) reported no difference in α-tocopherol concentrations in neck muscle of beef cows when 1,000 IU of vitamin E/d from all *rac* α-tocopheryl acetate (909 mg of α-tocopherol) or 1,000 IU of vitamin E/d from D-α-tocopherol (671 mg of D-α-tocopherol) was fed. Data from both these studies are equivocal because the quantity of vitamin E supplemented may have resulted in saturation of muscle. Biopotency studies should be conducted at supplementation rates that do not result in tissue saturation.

Experiment 2

Lamb Performance and α-Tocopherol in Meat. Performance was not different ($P > 0.15$) among treatments except for a slightly lower ($P < 0.10$) initial BW for lambs on the 300 IU/d for 21 d treatment compared with that for lambs on the 300 IU/d for 7 d treatment (Table 4). Supplementing 300 IU/d of vitamin E during the final 1 or 3 wk of the finishing phase increased ($P < 0.01$) longissimus α-tocopherol concentrations compared to lambs fed 15 IU/d during the entire finishing phase (Table 4). Lambs fed 300 IU of vitamin E/kg of DM for 21 d had higher ($P < 0.01$) longissimus α-tocopherol concentrations than lambs fed 300 IU/kg for 7 d. Longissimus α-tocopherol concentrations from lambs fed the 15 IU/kg treatment were within one standard error of the mean obtained in Exp. 1 with the same treatment. The concentration of α-tocopherol in longissimus from lambs fed 300 IU/d in Exp. 1 (70-d feeding period) were 2.2 and 1.4 times greater than concentrations from lambs in Exp. 2 fed 300 IU/kg for either 7 or 21 d. Maximum α-tocopherol concentration in longissimus from beef steers required 84 to 126 d (depending on dietary vitamin E concentration) of vitamin E supplementation (Arnold et al., 1993). Liu et al. (1995) proposed that the ideal concentration of α-tocopherol (minimum that yields almost maximal suppression of lipid oxidation) in beef longissimus was about 3.5 mg/kg of fresh weight. If this value is appropriate for longissimus of lambs, feeding 300 IU of supplemental vitamin E/kg of DM for either the last 7 or 21 d of the finishing period was not adequate. Regressing the duration of feeding diets with 300 IU of supplemental vitamin E/kg (Exp. 1, 70 d, Exp. 2, 7 or 21 d) on α-tocopherol concentrations in longissimus yielded the equation, Concentration (mg/kg wet weight) = 1.87 + 0.035d ($P < 0.01$; SE slope = 0.005) where d = duration of supplementation in days. Based on that relationship, a diet with 300 IU of supplemental vitamin E/kg would have to be fed for approximately 47 d to obtain longissimus concentrations of approximately 3.5 mg α-tocopherol/kg wet weight.

Retail Cuts, pH, Color, and Subjective Measurements. Based on visual appraisal, lean color and overall acceptability for loin chops and semimembranosus steaks became less desirable ($P < 0.01$) with time (i.e., score decreased), but no treatment by storage time interactions were observed (Table 5). Semimembranosus steaks from lambs fed 300 IU supplemental vitamin E/kg for either 7 or 21 d tended ($P < 0.10$) to have more desirable lean color than steaks from lambs fed the 15 IU/kg diet. Overall appearance of loin chop or semimembranosus steak was not affected ($P < 0.16$) by amount or duration of vitamin E supplementation. The limited treatment effects (or treatment by time interactions) could be caused by lack of sensitivity of the visual appraisal or because longissimus α-tocopherol concentrations were not different enough to elicit a response. Arnold et al. (1992) reported no difference in visual

Table 5. Visual appraisal of loin chops and semimembranosus steaks (Exp 2)[a]

Days displayed	Treatment[b]			SEM	Contrasts ($P <$)[c]	
	15 IU	300 IU (7 d)	300 IU (21 d)		SUP	DUR
Loin chop (longissimus muscle)—lean color						
1	6.1	5.6	6.7	0.30		
3	4.4	4.5	5.2	0.30		
6	3.6	3.9	4.0	0.30		
Mean	4.7	4.7	5.3	0.22	0.35	0.12
Loin chop—overall appearance						
1	7.0	6.7	7.2	0.28		
3	4.8	5.1	5.4	0.28		
6	3.3	3.9	3.9	0.28		
Mean	5.0	5.2	5.5	0.16	0.20	0.30
Semimembranosus steak—lean color						
1	6.3	6.3	6.8	0.35		
3	4.7	5.7	5.1	0.35		
6	2.6	4.2	3.5	0.35		
Mean	4.6	5.4	5.1	0.24	0.10	0.50
Semimembranosus steak—overall appearance						
1	7.3	7.7	7.5	0.43		
3	5.0	6.5	5.2	0.43		
6	2.3	3.6	2.9	0.43		
Mean	4.9	5.9	5.2	0.30	0.16	0.19

[a]Lean color evaluated on a 1 (extremely dark brown) to 8 (bright cherry red) scale. Overall appearance scored on a 1 (extremely undesirable) to 8 (extremely desirable) scale. Day effect ($P < 0.01$) but no day by treatment interaction ($P > 0.20$) for all measures.

[b]15 IU = 15 IU of supplemental vitamin E/kg DM during the finishing phase; 300 IU (7 d) = 15 IU of supplemental vitamin E/kg of DM and then 300 IU/kg of DM during the last 7 d of the finishing phase; 300 IU (21 d) = 15 IU of supplemental vitamin E/kg of DM and then 300 IU/kg of DM during the last 21 d of the finishing phase.

[c]SUP = contrast comparing 15 IU treatment to the two 300 IU treatments; DUR = contrast comparing duration of 300 IU/d vitamin E supplementation, NS = $P > 0.15$.

color score of longissimus lumborum steaks from steers fed 0 or 500 IU of supplemental vitamin E/d, although most other measures of oxidation and color were significantly improved with supplemental vitamin E. The concentrations of α-tocopherol in longissimus of these lambs also may not have been adequate to observe visual differences in color. The highest mean α-tocopherol concentration was 2.89 mg/kg of wet matter, which was lower than the ideal concentration for beef.

No differences ($P > 0.15$) were observed among treatments for pH of the semimembranosus steaks during the 6 d meat case storage (data not shown). Day of storage had an effect on pH ($P < 0.01$), but no discernable temporal pattern was evident, and values did not differ greatly. Mean pH values (treatment-day combinations) ranged from 5.52 to 5.69.

The L* color (a higher number indicates more white than black) of semimembranosus steaks was affected by storage time ($P < 0.01$). The overall treatment effect, the individual treatment contrasts, and the time by treatment interaction were not significant ($P > 0.30$). Most of the time effect appeared to occur between d 0 and d 1 (Figure 2). Both the a* (indicating an increase in green color relative to red) and b* color (indicating an increase in blue color relative to yellow) decreased ($P < 0.01$) as storage time increased (Figure 2). Treatment affected a* ($P < 0.02$) but not b* ($P > 0.12$). A time by treatment interaction was observed for both a* ($P < 0.05$) and b* ($P < 0.02$). The interaction was examined further using regression analysis. The natural log transformation of a* resulted in the best fit (lowest root mean square error) over time. The equations for the 15 IU of vitamin E/kg, 300 IU/kg for 7 d, and 300 IU/kg for 21 d treatments were $a^* = 21.4e^{-0.152d}$ (SE for slope = 0.011), $a^* = 22.6e^{-0.106d}$ (SE for slope = 0.007), and $a^* = 22.3e^{-0.105d}$ (SE for slope = 0.010) where d = day of display. The a* color of semimembranosus steaks decreased more rapidly (indicating a more rapid increase in green color relative to red) during display storage for the 15 IU of vitamin E/kg treatment than for the treatments with 300 IU/kg. The b* color decreased linearly ($P < 0.01$) over display time for the two treatments with 300 IU of vitamin E/kg with slopes of –0.343 (SE = 0.061) and –0.458 (SE = 0.068) for the 7 and 21 d treatments, respectively. The b* values for the 15 IU of vitamin E/kg treatment did not decrease linearly ($P > 0.23$), but a quadratic relationship was found ($b^* = 12.9 - 1.054d + 0.148d^2$; d = display d, SE for linear slope = 0.339, SE for quadratic slope = 0.054; $P < 0.04$). The marginal change in b* over time (i.e., the first derivative of the equation) was $-1.054 + 0.296d$. The b* color of semimembranosus steaks decreased more rapidly (indicating a more rapid increase in blue color relative to yellow) for the 300 IU of vitamin E/kg treatments than it did for the 15 IU/kg treatment. Treatment effects on a* and b* readings agree with the trend ob-

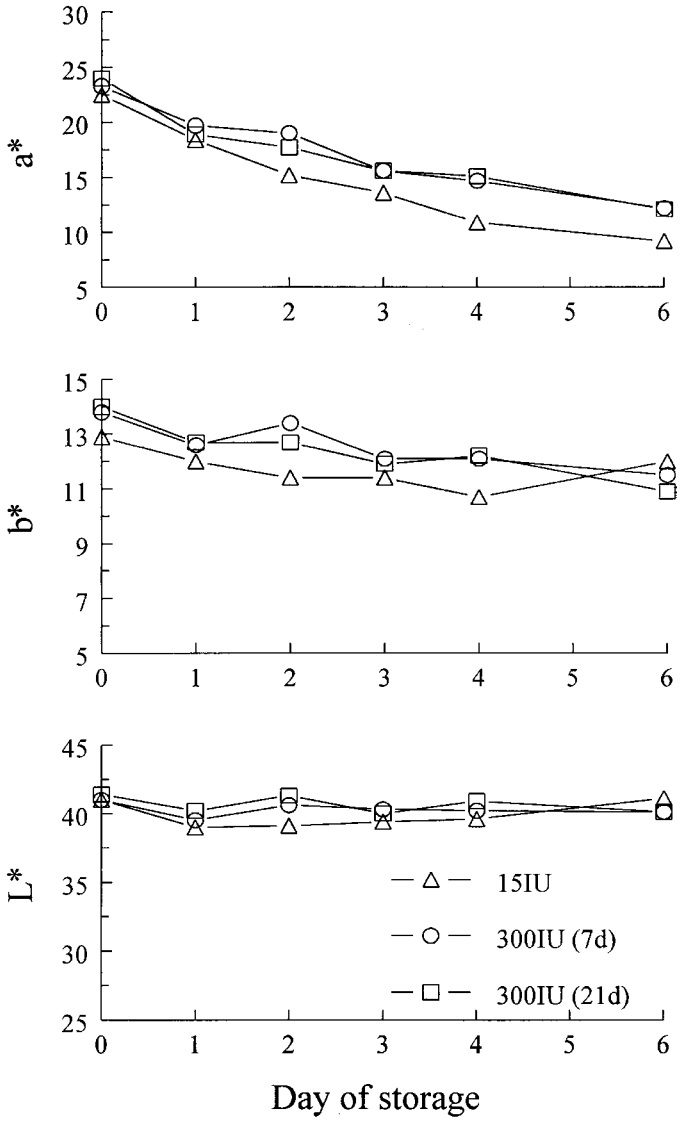

Figure 2. Effect of vitamin E supplementation on changes in color readings of semimembranosus steaks of lambs during display case storage. Treatments were 15 IU = 15 IU of supplemental vitamin E/kg of dietary DM fed during the finishing phase; 300 IU (7 d) and 300 IU (21 d) = 15 IU of supplemental vitamin E/kg of diet DM until the last 7 or 21 d of the finishing period when 300 IU of supplemental vitamin E/kg was fed. Each point represents a treatment mean. Standard errors for a*, b*, and L* were 0.58, 0.38, and 0.69.

served for visual appraisal of lean color of semimembranosus steaks (Table 5).

Although α-tocopherol concentrations were not measured in semimembranosus steaks, the treatment effects for a* and b* color was probably caused by changes in tissue α-tocopherol concentrations. Lanari et al. (1993) reported that dietary vitamin E supplementation (620 to 2,100 IU/d) increased both the α-tocopherol concentrations in fresh beef longissimus lumborum and the a* color of the meat when frozen. The presumed mode of action is that α-tocopherol in muscle is necessary to delay metmyoglobin formation and discoloration (Faustman et al., 1989). Rate of metmyoglobin formation was slower in semimembranosus cuts stored for 6 d from lambs supplemented with 1,000 IU of vitamin E/kg DM for 13 weeks compared to lambs supplemented with 20 IU/kg DM (Guidera et al., 1997).

Implications

Increased consumption of α-tocopherol via supplemental vitamin E or by grazing pastures increased the α-tocopherol concentration of longissimus from lambs. Predicted maximum longissimus α-tocopherol concentrations occurred at an intake of approximately 584 IU of total vitamin E/d suggesting that supplementation above that amount does not affect α-tocopherol concentrations in muscle. Meat from lambs finished on pasture had α-tocopherol concentrations similar to that from lambs fed a concentrate diet with 150 IU of supplemental vitamin E/kg. Feeding concentrate diets with 300 IU of supplemental vitamin E/kg for 7 or 21 d prior to slaughter can increase α-tocopherol concentrations in longissimus. Although the amount of vitamin E supplemented in our experiment probably did not cause maximal concentrations of α-tocopherol in meat, we observed less lean discoloration during display case storage.

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